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Great Lakes Research Review: 1982 Annual Report

Great Lakes Science Advisory Board

Great Lakes Science Advisory Board
Report to the International Joint Commission

1982 Annual Report

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INTERNATIONAL JOINT COMMISSION

GREAT LAKES SCIENCE ADVISORY BOARD

November 16, 1982

International Joint Commission
Canada and United States

Commissioners:

The Great Lakes Science Advisory Board, in partial fulfillment of its responsibilities under the Great Lakes Water Quality Agreement of 1978, is pleased to submit its 1982 Annual Report on Great Lakes research.

The main objectives of this report are to determine how fully current research efforts are meeting the requirements of the Agreement and to identify research needs which are not adequately addressed by the existing effort. The Board reached certain conclusions and formulated recommendations regarding research needs. The Board also suggested a mechanism to help circumvent the delay in response to the IJC recommendations and to increase cost-effective cooperation among the implementing agencies.

Respectfully submitted,

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The appendices to this report are published in a separate volume, which may be obtained from the International Joint Commission at the Great Lakes Regional Office in Windsor, Ontario, Canada.

Summary

A research review was carried out by the Science Advisory Board to identify current research efforts related primarily to Great Lakes water quality. The aim of the review is to identify knowledge gaps in research so that in the future, funds can be channelled with improved efficiency to address these gaps. Thus, the review is an important tool for streamlining research and making it more cost-effective.

The Science Advisory Board requested from most of the larger research organizations in the Great Lakes basin project descriptions of their predominantly Great Lakes oriented research activities. The information received was entered into a computerized data base, allowing for ready access to and sorting of the information. The data were coded to be retrievable by subject area, problem type and keyword. The research needs identified by the 1978 Agreement and in recent Board reports were compared with current research activities.

The Board found that although most current research is being done to meet specific agency mandates, and is not initiated to meet needs arising out of the Agreement requirements, much of the research does respond, however, to needs identified within the Agreement. The Board also noted a trend towards more targeted research.

Based on efforts and resources expended on the various identified research needs, and the expertise of its members, the Board identified ten specific high priority research needs:

1) Epidemiological studies (human health)
2) Health of aquatic communities

3) Atmospheric pollution indicators
4) Polynuclear aromatic hydrocarbons (PAHs) and toxaphene
5) Structure-activity correlations
6) Tissue and sediment banks
7) Computer modeling and validation
8) Phosphorus management
9) Groundwater contamination
10) Socio-economic considerations

In addition, the Board determined that research is required to address the chronic pollution problems associated with the "areas of concern" (geographic locations in the Great Lakes system) identified in the 1981 and 1982 Annual Reports of the Water Quality Board.

In the course of performing the research review, the Board found that the present mechanisms to communicate research needs to potential implementing agencies are inadequate. To enhance communication and increase cost-effective cooperation and coordination among the Great Lakes research community, the Board recommends that a Council of Great Lakes Research Directors be established to interact with the Science Advisory Board and to translate the needs to the research community in more detail. The Council will also be able to assess how well existing efforts are meeting research needs.

Preamble

Great Lakes research is an integral part of the effort expended by the United States and Canada to preserve, restore and enhance the quality of water in the Great Lakes system. One purpose of Great Lakes research is to establish the relationships between water quality problems and their causes. Since water quality management strategies are based entirely on the understanding of these relationships, it is improbable that sound management decisions can be formulated in the absence of such research. With the signing of the 1972 and 1978 Great Lakes Water Quality Agreements, the United States and Canada agreed to develop research programs that deal effectively with Great Lakes water quality problems and to provide sufficient resources for implementing these programs.

Under these Agreements, the International Joint Commission (IJC) has special responsibilities and functions related to research. The Commission is to assist in coordinating water quality research efforts in the Great Lakes basin by identifying objectives for research activities and tendering advice and recommendations on research to federal, state and provincial governments. The Commission is also responsible for disseminating information about research to the public and appropriate agencies. The Agreement specifies that the Commission appoint a Great Lakes Science Advisory Board to assist it in reviewing research activities and to provide advice on other scientific issues under the Agreement.

In 1975 the Commission directed the Research Advisory Board (currently the Science Advisory Board) to review research activities in the Great Lakes basin and determine their adequacy, effectiveness and responsiveness to the requirements of the 1972 Agreement. The Board compiled and published documents on Great Lakes research activities in 1975, 1976 and 1978. It also held a workshop to identify Great Lakes research needs and the proceedings were published in 1976. All these documents are available to the public.

The Science Advisory Board presents in this document a comprehensive review of current research efforts conducted by the major research institutions in the Great Lakes basin. The Board examined the objectives of the institutions' research projects to determine the extent to which these projects are responding collectively to the requirements of the 1978 Agreement: namely, which research needs are adequately addressed and which issues still require more research. The Board also reviewed past research efforts of the same institutions to determine trends in research subjects over the last eight years.

The Board recognizes that many of the research institutions do not design their programs specifically to respond to the requirements of the Agreement. This review is not intended to criticize the choice of research projects by agencies. However, Article V Section 2(a) of the 1978 Agreement states that the "principal research funding agencies in both countries orient the research programs of their organizations in response to research priorities identified by the Science Advisory Board and recommended by the Commission." The Board, therefore, suggests that the IJC transmit the recommendations made in this report to the funding agencies so that the research direction required to meet current issues in the Great Lakes can be achieved.

The Board found that a significant amount of Great Lakes water quality research is being conducted, but that this research is not sufficient to address adequately the complex problems that currently face the Great Lakes. Meanwhile, resource allocations for government programs, including those which support many of the Great Lakes research activities, are limited. Wise use of available resources is therefore essential. Accordingly, it is imperative that research priorities be established and mechanisms for cost-effective international cooperation among research institutions be developed as outlined under Article V 2a and b of the 1978 Agreement.

Great Lakes Research

INTRODUCTION

Great Lakes research is frequently referred to as if it were a definable entity. In reality, Great Lakes research is highly subjective and has no discrete boundaries, either topically or geographically. Thus, what is studied outside the basin may have direct or indirect application in the Great Lakes. To pragmatically evaluate Great Lakes research, however, the Board reviewed the current research programs of only the major research institutions in the Great Lakes basin; assessed the projects' objectives as related to the requirements of the 1978 Agreement; and compared past with current research programs to determine trends.

To provide the Board with a definable product for evaluation, some constraints were required. Firstly, scientific efforts in which the primary purpose is to accumulate data by routine methods for regulatory or management needs were not considered as research. For example, documentation of dissolved oxygen concentrations in the lakes for the purpose of following trends, i.e. monitoring, was not included. Conversely, toxicity data generation, using routine protocols for validating chemical structure-activity relationships, were included. While both have similar routine work natures, the latter develops and validates a new method, whereas the former documents existing conditions at various times.

Secondly, the Board made a fundamental decision to limit the review to the largest research programs dealing mainly with Great Lakes water quality problems. The lack of sufficient resources and time made it impossible to contact all institutions conducting research pertinent to the Great Lakes. This decision excluded some relevant research being conducted within and outside of the Great Lakes basin. For example, the National Cancer Institute in the United States is developing techniques for identifying human carcinogens. These methods are of crucial importance when the hazard of

chemicals found in the Great Lakes is being assessed. Similarly, analytical methods for measuring low concentrations of organic chemicals in water and tissue are being developed or improved worldwide. The development and improvement of these methods are often directly applicable to measurements required in the Great Lakes. Unless such methods development originated in the Great Lakes basin, the work was not included in this report.

The Board emphasizes, however, that limited research can be conducted in any geographical location and have full applicability to the Great Lakes. There is a substantial part of the Great Lakes ecosystem that has unique characteristics. Therefore, research must either be done considering those specific characteristics or, in many cases, must be done physically in the basin. For example, while nutrient models for the coastal estuaries or other freshwater lakes are fundamentally similar, many of the rate constants and terms of the model must be made specific to the Great Lakes before they are valid predictors. Some of that data could only be obtained by work conducted in the basin. The Board urges the Commission to be cautious about assuming that many of the Great Lakes research needs will be satisfied by agency research efforts without a Great Lakes focus.

As the Board has pointed out in past annual reports to the Commission, the goals of the Agreement will not be met by attention to water quality alone. For example, the finest water quality attainable will not assure an abundance of highly desired fish species if these populations are overfished or if critical habitats such as spawning and nursery grounds are destroyed. The ecosystem concept proposed by the Board, recommended by the Commission, and adopted by the Parties requires that all the interacting components -- land, air, water and man -- must be taken into consideration if goals are to be met. So while the Board's evaluation is focused on "water quality" research, significant research efforts and accomplishments are being made in other areas equally important to the Agreement needs, such as fish population dynamics.

COMPLEXITY OF THE GREAT LAKES

The Great Lakes constitute an intricate freshwater ecosystem unparalleled in this world. They are of enormous geographical, spatial and temporal dimensions considering the extent of their drainage basins, water volumes and hydraulic retention times. The largest of these lakes is Superior with a basin and lake area of 209,789 square kilometers (81,000 square miles) and a hydraulic retention time of 183 years. The smallest is Lake Erie with a basin and lake area of 84,149 square kilometers (32,490 square miles) and a hydraulic retention time of 2.8 years. Approximately 30 percent of Canada's population and 20 percent of the United States' live in the Great Lakes basin and utilize its resources. Urbanization, industrialization and deforestation in the basin have caused environmental problems, particularly in the lower lakes; Erie and Ontario. These lakes have become polluted by a wide variety of industrial, municipal and agricultural wastes. The pollution has adversely affected water quality and aquatic resources.

Due to the complexity of the Great Lakes system, research scientists frequently encounter difficulties in identifying the cause and effects of many of the water quality problems encountered in these lakes. For example, the disappearance of valuable endemic species from some lakes and the discovery of certain contaminants in fish tissues are only two of the challenging questions facing Great Lakes scientists.

Water quality problems also vary in magnitude, effects and persistence. Some problems are localized in bays and estuaries, while others extend to open waters. Some problems, such as eutrophication, may affect the aesthetic qualities of the lakes but will not pose any danger to human health. Others, such as toxic chemicals, often present health hazards to humans and other organisms while having little visible effect on the water.

Scientists are aware of the interactions between contaminants and prevailing environmental factors. For example, biological reactions and the activity of certain chemicals are known to be affected by temperature and/or light intensity. There are also interactions among the contaminants

themselves. The presence of a wide variety of pollutants can result in additive, synergistic, or antagonistic effects. Finally, scientists realize that effective management solutions to Great Lakes water quality problems require accurate information on the economic and social implications of the available options. All the components of the Great Lakes, i.e. the entire ecosystem, should be taken into consideration when planning and conducting research on the Great Lakes.

The ecosystem approach has made researchers increasingly aware that water quality is not the only research issue in the Great Lakes. Projects investigating atmospheric deposition, groundwater contamination, shoreline erosion and agricultural practices, for example, have been implemented in order to quantify the impacts of these factors on the Great Lakes ecosystem. Recent concern that degraded Great Lakes water quality may adversely affect human health has spurred research into all components of the food chain including unicellular plants, zooplankton, fish and man. Each food chain compartment presents unique chemical and biological problems.

Investigations into the fate of discharged pollutants are important. Fate information is needed to understand how excess amounts of algal stimulants reach open water from their river basin source and to predict the recovery time for a body of water, once these stimulants are removed. Furthermore, knowledge regarding the accumulation, the ultimate fate, and the impacts of persistent toxic chemicals is also needed.

The complexity of these issues warrants a large amount of research specific to the Great Lakes. If research is not adequate, it will be difficult to identify problems, understand the cause-effect relationships, predict ecosystem responses or behaviour, and ultimately improve the management of the Great Lakes. It is important to detect as early as possible subtle changes in water quality. Once problems have become obvious, solutions and recovery may take decades. If the problem is irreversible, recovery may never occur.

SURVEILLANCE, RESEARCH AND MANAGEMENT

Throughout the history of science as conducted on the Great Lakes ecologists have used a wide variety of techniques, typically research coupled with surveillance and management activities, to understand and control man's impact on these remarkable bodies of water. Well-known examples of useful management techniques that have been based on research and existing scientific knowledge about the Great Lakes ecosystem include limiting phosphorus loadings from industrial and municipal sources to reduce the growth of nuisance algae in the lakes; using highly selective larvicides to control the devastating sea lamprey; and imposing restrictions on the use of specific toxic substances.

Surveillance and its companion discipline, monitoring, contribute along with research to the understanding of Great Lakes processes. The management of such an enormous resource, however, is dependent upon appropriate mixtures of both surveillance and research. In fact, effective management cannot exist in the absence of either.

Surveillance and monitoring are typically concerned with the current state of the aquatic resource. They measure improvement (or lack thereof) of the resource in the light of historical data or in comparison with criteria or objectives. Research, however, is usually looking forward, even in its use of retrospective data. In the absence of research, surveillance and monitoring cannot provide a connection between an outcome and its cause.

RESEARCH TRANSFER

Pollution abatement is a costly process. In this time of diminishing resources, the need has never been greater for pollution control practices to be cost effective. Research minimizes trial-and-error applications and the waste of resources that such imprecise activities entail. Given declining resources, the need for both the proper selection and a high quality of research increases.

If the research is broad enough in scope, its results are expected to have applicability beyond the immediate time and place of concern. This function has been called research transferability. Scientific research has been steeped in the concept of transferability and the tradition of applicability to other bodies of water, both fresh and marine, throughout North America and beyond.

In many instances the Great Lakes research community has provided a transferable level of scientific expertise and understanding which has led the world. Such contributions have included data for the establishment of national environmental criteria; implementation of legislation to remove specific environmental toxicants from national marketplaces; identification of new threats to public health, that have national applicability in both the United States and Canada; and even new knowledge which contributed to the welfare of public health.

RESEARCH ACCOMPLISHMENTS

Over the last two decades, Great Lakes research scientists have investigated several water quality problems and addressed many issues of concern to the public. A partial list of major research accomplishments follows:

- Early efforts directed toward defining the problem of eutrophication in the lower Great Lakes quantified the correlation between the extensive areas of hypolimnetic deoxygenation with excessive nutrient additions. Such techniques for correlating this phenomenon were subsequently adopted, with modifications, by other researchers throughout the world.

- Subsequent consideration of the problem of nutrient additions provided the first useful information on the biological availability of these compounds, especially phosphorus. This information led to detergent phosphate control in most Great Lakes jurisdictions.

- As a result of the availability of large volumes of accurate time-series data on nutrient loadings to the Great Lakes, the use of numerical simulation enabled the development of estimates of "target" loadings to achieve maximum benefit to the ecosystem at the lowest possible cost for control. Since its inception on the Great Lakes, this concept has achieved wide acceptance.

- Investigations into the bio-accumulation potentials of fish in the Great Lakes, and the subsequent development of a predictive mathematical model for Lake Michigan, have supported a national ban on the use of the pesticide DDT in the United States.

- Orally ingested asbestos was shown to be present in the urine of exposed individuals indicating that asbestos can pass across membranes and throughout the body. These findings contributed in a substantial way to the international understanding of disease resulting from oral exposure to asbestos. This substance has been included in the EPA list of priority pollutants.

- Polychlorinated biphenyls (PCBs) were identified as major environmental contaminants in Great Lakes samples. This identification led to national searches for the compounds and an ultimate ban on their use in both the United States and Canada.

- Research efforts on the Great Lakes demonstrated to the world the extent of toxicity problems associated with compounds whose persistence is measured in terms of decades. The extent of the problem was documented by the poor reproductive rates for Lake Ontario herring gull populations.

- Research data acquired on the Great Lakes have linked the transport of hazardous substances to atmospheric sources. Recently, data from a remote island site in Lake Superior, values from the open waters of Lake Michigan, and levels in atmospheric precipitation provided the impetus for a national limitation in the use of the pesticide

toxaphene in the United States (The use of toxaphene is stringently restricted in Canada).

While the achievements from Great Lakes research have been impressive, several important problems remain. Chemical residues in edible fish have produced headlines in the media for the past 10 to 12 years. Some of these residue-formers such as DDT and PCBs have been removed from use. Several hundred more chemicals are known to occur as residues in fish or birds, but the concentrations for some and the health significance for most are unknown. Only through research can the significance of these chemicals be determined and subsequent controls established. Their effect on the health of aquatic organisms and consumers of aquatic organisms, such as mink, is also unknown. Polynuclear aromatic hydrocarbons (PAHs) and toxaphene are among those potentially significant chemical residues for which only meagre information exists.

There are not enough resources to test all of the tens of thousands of chemicals in use in the basin today. A method for determining their priorities based on the probable degree of hazard must be found. It may be possible to use chemical structure to estimate toxicity and hazard. If so, hazard assessment could be greatly accelerated and costs greatly reduced.

Without going into details, other important research needs include validation of mathematical models, the establishment of specimen banks, the investigation of groundwater contamination and atmospheric inputs. All are problems of high priority. While some of these issues have aspects that can be researched outside the basin, a large part of the research will have to be completed in the basin by Great Lakes scientists.

RESEARCH INSTITUTIONS

Among the institutions in the basin conducting research on Great Lakes water quality problems (see IJC 1976 Directory of Great Lakes Research and Related Activities), some are funded and operated by government agencies, while others are affiliated with academic institutions or operated under the

auspices of public organizations and private enterprises. In many cases the main interest of the institution is not Great Lakes water quality per se but certain components of the Great Lakes environment which could be affected by water quality, e.g. fisheries. Such research efforts are advantages to Great Lakes water quality research.

In this research review, the Board placed emphasis on government institutions that deal mainly with Great Lakes water quality problems. These institutions not only produce in-house research of international renown, but also provide a source of funding and expertise to universities and private organizations both within and outside the basin boundaries. The Board selected a few of the federal research institutions, some in Canada and some in the United States (Figure 1), to exemplify their research capabilities and expertise in the basin.

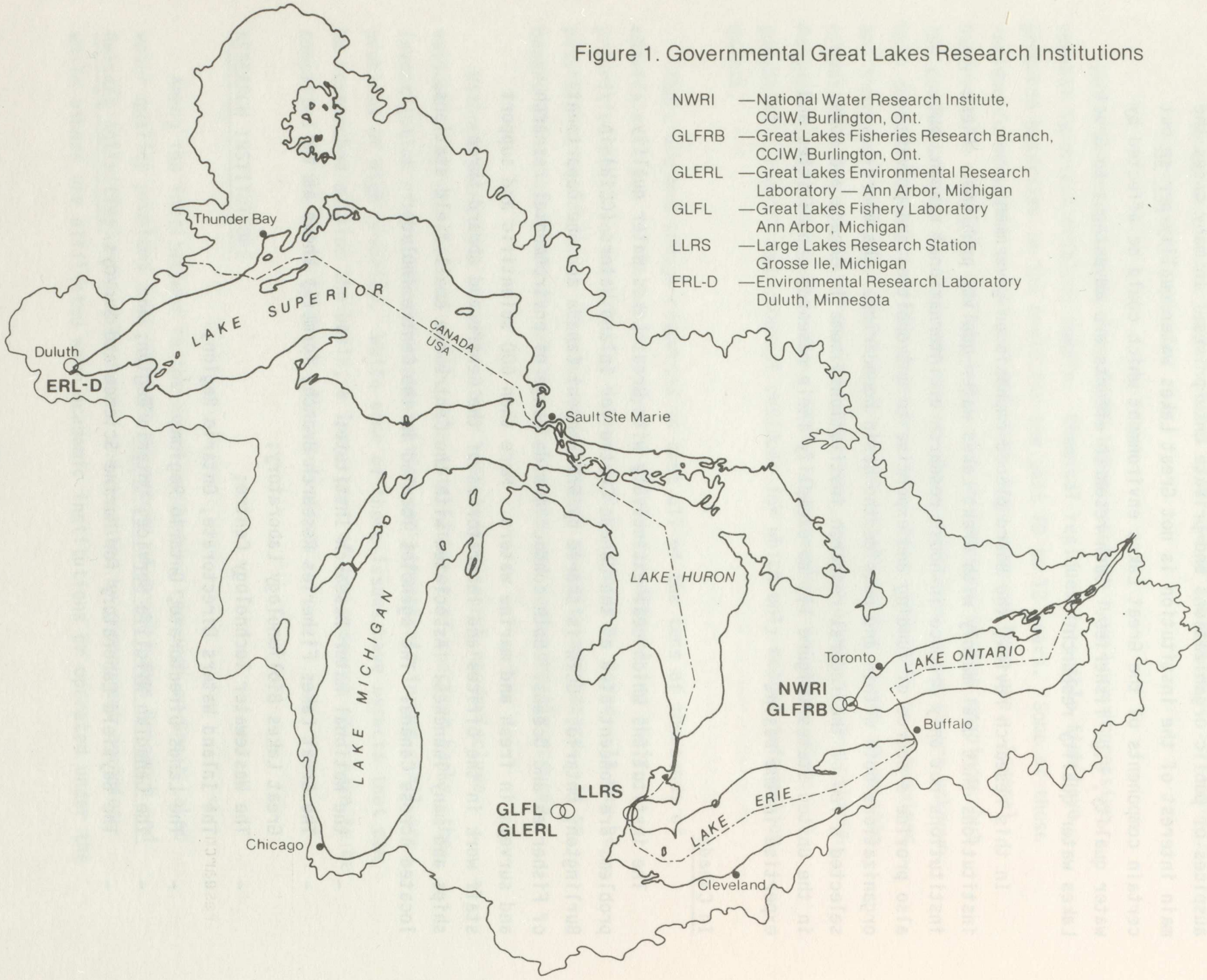
In Canada

The institutions which deal extensively with Great Lakes water quality problems are concentrated at the Canada Centre for Inland Waters (CCIW) in Burlington, Ontario. CCIW is shared by Environment Canada and the Department of Fisheries and Oceans. Both conduct a wide range of environmental research and surveys in fresh and marine waters. More than 600 scientific and support staff work in the offices and laboratories of the Centre and aboard three ships and many launches. Associated with the Centre are small field stations located across Canada. The agencies located in the Centre include:

- the National Water Research Institute;
- The Great Lakes Fisheries Research Branch, formerly known as the Great Lakes Biolimnology Laboratory;
- The Wastewater Technology Centre;
- The Inland Waters Directorate, Ontario Region;
- The Lands Directorate, Ontario Region;
- The Canadian Wildlife Service, Ontario Region; and
- The Bayfield Laboratory for Marine Science and Surveys.

Figure 1. Governmental Great Lakes Research Institutions

NWRI —National Water Research Institute, CCIW, Burlington, Ont.
GLFRB —Great Lakes Fisheries Research Branch, CCIW, Burlington, Ont.
GLERL —Great Lakes Environmental Research Laboratory — Ann Arbor, Michigan
GLFL —Great Lakes Fishery Laboratory Ann Arbor, Michigan
LLRS —Large Lakes Research Station Grosse Ile, Michigan
ERL-D —Environmental Research Laboratory Duluth, Minnesota



The National Water Research Institute (NWRI) and the Great Lakes Fisheries Research Branch (GLFRB) are the major federal government contributors to Great Lakes water quality research in Canada. In the 1981-82 and 1982-83 fiscal years, NWRI spent over two million dollars annually on Great Lakes research. To meet its overall purpose, NWRI consists of six major program divisions: Analytical Methods, Environmental Contaminants, Aquatic Physics and Systems, Hydraulics, Aquatic Ecology, and Technical and Administrative Support. The combined efforts of these divisions provide information on water systems in Canada, with special emphasis on Great Lakes water quality problems such as pollution and resources development.

The Great Lakes Fisheries Research Branch serves the Ontario Region of Pacific and Freshwater Fisheries, Department of Fisheries and Oceans. Its main research efforts are directed toward the effects of man's activities on the Great Lakes ecosystem, particularly biota, but also water and sediment. It employs 44 people and prior to 1979 had a total budget (including salaries) of approximately one million dollars. By 1982-83 its total budget had increased to approximately two million dollars. Of this amount, about 90% is devoted to Great Lakes research and surveillance. GLFRB is organized into three programs: Surveillance, Environmental Toxicology, and Ecosystem Studies.

Vessels in support of CCIW's Great Lakes programs are provided by the Bayfield Institute of Marine Science and Surveys, part of Fisheries and Oceans Canada. These include three open lake survey vessels and sixty assorted launches.

In the United States

A significant amount of Great Lakes water quality research in the United States is carried out by three federal laboratories:

- the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan;
- the Environmental Research Laboratory-Duluth mainly through its Large Lakes Research Station located in Grosse Ile, Michigan; and
- the Great Lakes Fishery Laboratory in Ann Arbor, Michigan.

The Great Lakes Environmental Research Laboratory (GLERL) is a part of the United States Department of Commerce, National Oceanic and Atmospheric Administration (NOAA). It conducts integrated, interdisciplinary environmental research in support of resource management and environmental services in coastal and estuarine waters with a special emphasis on the Great Lakes; performs field, analytical and laboratory investigations to improve understanding and prediction of coastal and estuarine processes and interdependencies with the atmosphere, land and sediments; places special emphasis on a systems approach to problem oriented environmental research; and provides assistance to resource managers and others in obtaining and applying the information and services developed by the laboratory.

This laboratory conducts investigations on hydrology, synthetic organic and particle dynamics, ecosystem and nutrient dynamics, physical limnology, and meteorology and environmental systems studies of the lakes, their basins and the overlying atmosphere. The ultimate goal of the program is to understand the lake-land-atmosphere system so that environmental simulation and prediction models can be built to provide sufficiently precise information on Great Lakes processes and phenomena to support enlightened use of the region's resources. Now in its eighth year, this laboratory has a 4.1 million dollar budget and employs approximately 50 full-time and 15 to 40 part-time staff.

GLERL recently began a cooperative research program with the Universities of Michigan and Minnesota to predict the environmental consequences of persistent synthetic organic contaminants in aquatic ecosystems. Considerable research is supported at a variety of institutions including:

- Argonne National Laboratory
- Clarkston College
- Duke University
- Manhattan College
- Michigan State University
- University of Michigan
- University of Minnesota

- State University of New York
- University of Wisconsin

Facilities include one major research vessel and three launches, a computer laboratory, a marine instrumentation laboratory, a chemistry laboratory, a biology laboratory, an ice laboratory, and a particle dynamics laboratory.

The Environmental Research Laboratory-Duluth (ERL-D) is a major aquatic research laboratory under the direction of the Office of Research and Development, United States Environmental Protection Agency (U.S. EPA). This laboratory has an annual budget of approximately 6.5 million dollars with a staff of 85. The primary research function of ERL-D is the development of water quality criteria for freshwater uses in the United States.

The Large Lakes Research Station (LLRS), which operates under the auspices of the ERL-D, focuses its research activities mainly on the mathematical modeling of physical, chemical and biological processes within the Great Lakes. This station has complete computer facilities and comprehensive capabilities for data collection and processing. It has a full-time staff of four employees, but utilizes the expertise of many specialized scientists on a contract basis. Its budget is approximately 2.5 million dollars, 80 percent of which is used to support research at other research institutions. LLRS operates a major research vessel and two small crafts in the Great Lakes. Institutions supported include the following:

- University of Michigan, Great Lakes Research Division;
- Ohio State University;
- New York State Department of Health;
- Case Western Reserve University;
- State of Michigan Department of Public Health;
- Clarkston College;
- Manhattan College, Department of Environmental Science and Engineering;
- State University of New York, College at Buffalo and College at Albany;
- University of Michigan, Civil Engineering Department; and
- University of Minnesota.

The Great Lakes Fishery Laboratory (GLFL) is a part of the United States Department of the Interior's Fish and Wildlife Service. All the research it administers is aimed at solving problems associated with the maintenance, enhancement and protection of the fishery resources in the Great Lakes. Now in its 55th year, the GLFL conducts research on transboundary fish communities, with emphasis on the effects of major factors -- man-induced and ecological -- that govern the status, performance and productivity of component stocks. Factors being addressed include harvest of fish stock for commerce and recreation; fish used as forage by other fishes; fish predation by the sea lamprey; and alteration of habitat through contamination, reduced (physical) carrying capacity, and diminished water quality in general. With 76 full-time staff, 14 part-time employees, and a budget in FY 1982 of just under three million dollars, it has the following facilities:

- the Ann Arbor (headquarters) Laboratory on the North Campus of the University of Michigan;
- the Ashland Biological Station and Bayfield Vessel Base in Wisconsin;
- the Cheboygan Vessel Base in Michigan;
- the Saugatuck Vessel Base in Michigan;
- the Sandusky Biological Station and Vessel Base in Ohio;
- the Oswego Biological Station and Vessel Base in New York; and
- five (45'-75') research vessels, one on each of the Great Lakes, for open-lake research, as well as various small craft for operations nearshore or in bays and rivers.

Other Institutions

In addition to the federal institutions described above, the Province of Ontario and the Great Lakes states - Michigan, Illinois, Wisconsin, Ohio, Minnesota, Indiana, Pennsylvania and New York - maintain laboratories which contribute in varying degrees to Great Lakes research. However, these laboratories are not dedicated solely to Great Lakes research; therefore, they are not included in this Section.

Research Review

INTRODUCTION

The main objective of this review is to determine the extent to which current research efforts are collectively responding to the requirements of the 1978 Great Lakes Water Quality Agreement. Accordingly, attempts are not made to examine research efforts on an individual basis. The Board recognizes that there are more than one hundred and fifty institutions among government, academic and private organizations involved in research dealing directly or indirectly with some aspect of the Great Lakes. About forty of these institutions address water quality issues. The remaining institutions are customarily involved in other aspects of the Great Lakes, such as fisheries biology, land use planning, geographical and meteorological studies; and they are seldom involved with water quality.

After careful consideration, the Board decided to limit this year's review to those institutions which are known to be undertaking the majority of Great Lakes water quality research. In making this decision, the Board recognizes that some research institutions which may be undertaking relevant water quality research may be overlooked in this year's review. Attempts will be made, however, to include such institutions in future reviews.

COLLECTION OF INFORMATION

The Board contacted thirty-three research institutions which are known to be carrying out the majority of Great Lakes water quality research, and requested them to provide information on their current projects (Appendix I - Correspondence A)*. The information requested included:

* The Appendices to this report are published in a separate volume, which may be obtained from the International Joint Commission at the Great Lakes Regional Office in Windsor, Ontario, Canada.

- the name of the funding or supporting organization;
- the name of the performing organization and the name(s) of the principal investigator(s);
- titles of research projects, their objectives and the anticipated benefits;
- funding for each project in each fiscal year;
- duration of each project and person years; and
- additional information useful to this review.

Twenty-five institutions, fifteen in the United States and ten in Canada, provided all or most of the requested information (Appendix II). Two institutions did not respond and the remainder indicated that currently they are not engaged in Great Lakes water quality research.

The Board also reviewed past research to determine the trends in research subjects over the last decade. To obtain information on previous research efforts, the Board referred to the 1976 IJC Directory of Great Lakes Research and Related Activities. This document provides descriptions of Great Lakes research projects conducted by various institutions during the period 1974-1977. For the purpose of comparison, the Board considered only those projects conducted by the same institutions which provided information on their current research.

IDENTIFICATION OF ISSUES

The Board reviewed the 1978 Agreement and past reports of the IJC and its advisory boards to identify research issues. These issues reflect Great Lakes water quality problems which are of concern to Great Lakes users. Some of these issues are requirements of the Agreement; others are mainly recommendations based on studies and research reviews previously conducted by or for the Commission. Results of this review are summarized in Appendix III.

The Board found that all of the research issues outlined in the Agreement and in the past reports have focused on six specific Great Lakes problems: toxic organics, toxic metals, phosphorus, other nutrients, pathogens and

thermal discharges. Although phosphorus is a nutrient, it was considered as a separate issue because of its importance as a limiting factor in the problem of eutrophication. Some of the projects reviewed deal with more than one problem, a few others deal with issues different from the ones identified above, and some project descriptions are not explicit enough to identify the problem being investigated. The Board, however, was able to include all these projects in this review by developing a special classification and coding system, described below.

CLASSIFICATION OF ISSUES

The information received from the various organizations varied widely in format and in the degree of detail provided for each research project. For the purpose of this review, it was essential to summarize the information in a standardized form and to develop a flexible computer program for its storage and retrieval. The Board, therefore, developed a classification and coding system for the identification of Great Lakes "problems" and the "subjects of research" (Table 1). This classification is based on the research needs identified in Appendix III. The system also identifies the activities under which research projects may fit within the requirements of the 1978 Great Lakes Water Quality Agreement. These activities generally determine the "source" of the problem. The approach used in the development of this classification and coding system is described in detail in Appendix IV.

As indicated above, by reviewing the Agreement and previous IJC recommendations, the Board identified six specific problems which are used in this classification. In addition, projects dealing with specific problems not mentioned above, are classified as "others". This group includes projects dealing with current measurements, erosion studies, etc. Projects not specifying the exact nature of the problem under investigation are classified as "unspecified". Projects addressing more than one problem are classified as "several".

TABLE 1

CLASSIFICATION AND CODING OF RESEARCH ISSUES

A. RESEARCH PROBLEM	CODE
Toxic organics	A
Toxic metals	B
Phosphorus	C
Nutrients	D
Contaminants - general	E
Pathogens	F
Thermal discharges	G
Other	H
Unspecified	I
Several	J

B. RESEARCH SUBJECT	CODE
Source and loading	0
Characteristics	1
Fate and transport	2
Environemtal impacts	3
Human health effects	4
Method development and modeling	5
Criteria	6
Management	7
Other	8
Unspecified	9

C. ACTIVITY (SOURCE)	CODE
Atmospheric	a
Dredging	b
Industrial	c
Municipal	d
Shipping	e
Non-point	f
Other	g
Unspecified	h
Several	i

The classification system also describes the subject of research. It includes the following:

Source and Loading - Determination of sources of problems and quantities of pollutants reaching the lakes.

Characteristics - Determination of the properties of problems.

Fate and Transport - Determination of fate and movement of pollutants in the environment.

Environmental Impacts - Determination of impacts on living and non-living components of the lakes.

Human Health Effects - Estimates of impacts on human health.

Method Development and Modeling - Development of new techniques to identify and measure problems and to predict and simulate their behaviour in the environment.

Criteria - Development of objectives, standards and regulations.

Management - Development of cost-effective management strategies and control programs.

The classification system also relates each problem to one or more of the activities or sources of problems outlined in the Agreement, including atmospheric, dredging, industrial, municipal, shipping, non-point, other (describing investigations related to none of the above, such as hydrological studies, and current measurements), unspecified sources, and several sources.

In addition to the classification system described above, a set of keywords is used to identify the specific aspects of each study. Keywords

include names of specific pollutants under investigation, environmental components being examined, location of study area, etc.

All of the information described above is stored in a computer system and is retrievable by problem type, subject area, keyword, funding organization and performing organization (Appendices IV and V). This information constitutes the data base used in this review.

VERIFICATION OF PROJECT CLASSIFICATION

After the projects were classified and coded, only summaries of the current research projects were returned to their respective institutions for verification of the information (Appendix 1, Correspondence B). Any recommended changes were incorporated in the data base. The Board contends it would be extremely difficult for the institutions to refer back to their past records and to question scientists in order to verify the historical information. Accordingly, the historical information was not verified.

Results

INTRODUCTION

Several inherent limitations of the data base (Appendices V and VI) must be noted before a meaningful discussion of this review proceeds. This review is not intended to account for every research project that addressed directly or indirectly some aspect of the Great Lakes, but only to include the majority of the research that is pertinent to Great Lakes water quality issues. The 25 research institutions included in this review account for the majority of the pertinent research. Since some of these institutions provide substantial funds to other groups, such as grants to colleges and universities, the coverage of the review has actually extended beyond the 25 institutions contacted.

The institutions provided the Board with pre-prepared project descriptions and workplans. The specificity and completeness of these workplans varied widely among the respondents, particularly since the Board did not request a standardized format. Further, decisions as to what constituted water quality research pertinent to the Great Lakes was decided by the staff of the responding organizations. Undoubtedly, there were substantial variations in these decisions.

The amount of detail provided by the responding institutions also varied. The projects were categorized based on the available information. Undoubtedly, more detail would have caused some projects to be classified differently.

Given these limitations, it is not practicable to distinguish slight differences in research emphasis from year to year or differences between the efforts of the various organizations. The data base is useful, however, and sufficient to determine general trends in research subjects over the last eight years, and to provide an overview of resources allocated for Great Lakes research.

After careful examination of the data base, the Board found that few institutions provided information on projects for 1983 and 1984. Most of the institutions were, understandably, hesitant to provide descriptions of programs which have not yet been authorized. Similarly, the 1976 Directory which was used as a source for the historical information did not include descriptions of many of the projects conducted in 1974 and 1977. The Board, however, found the information for the current period 1981-1982 and for the historical period 1975-1976 to be comprehensive and sufficient for the purpose of this review. Accordingly, the review is limited to projects conducted in the two periods 1975-1976 and 1981-1982.

WATER QUALITY PROBLEMS

The Board reviewed descriptions of a total of 451 projects representing current research projects for 1981 and 1982 and a total of 535 projects representing past (historical) research for 1975 and 1976. The results of this review are summarized in Tables 2 and 3, respectively. It is clear that current and past research has been addressing the six specific problems identified by the Board. A large number of projects (approximately 27 percent of the current and 17 percent of the historical), however, have been addressing contaminants in general, without any indication as to whether these contaminants were organic or inorganic in nature. The Board also found that past research was less specific as to the exact nature of the problem being investigated than was current research. Approximately 26 percent of the historical projects had addressed problems "other" than the specific issues identified by the Board including suspended solids, erosion, waves, currents and hydrology. Approximately 16 percent of the current projects are addressing such topics.

Considering the number of projects addressing each of the specific problems identified above, the Board has drawn several conclusions.

TABLE 2
CURRENT RESEARCH PROJECTS IN THE GREAT LAKES
(BY SUBJECT OF RESEARCH, 1981 AND 1982)

RESEARCH SUBJECTS	TOXIC ORGANICS	TOXIC METALS	PHOSPHORUS	NUTRIENTS	CONTAMINANTS - GENERAL	PATHOGENS	THERMAL DISCHARGES	OTHER	UNSPECIFIED	SEVERAL	TOTAL
NUMBER OF PROJECTS	94	25	17	23	122	14	5	73	25	53	451*
AS A % OF THE TOTAL	21 %	6 %	4 %	5 %	27 %	3 %	1 %	16 %	5 %	12 %	
NO. OF PROJECTS DEALING WITH:**											
Source and Loading	11	3	4	8	21	6	0	6	0	12	71
Characteristics	18	5	1	1	7	1	0	6	0	4	43
Fate and Transport	45	11	8	10	39	5	1	24	1	23	167
Environmental Impacts	26	11	5	17	31	1	3	14	4	18	130
Human Health Effects	6	1	0	0	1	2	0	1	0	7	18
Method Dev. & Modeling	45	10	5	7	44	1	0	24	4	20	160
Criteria	6	3	0	1	9	2	0	3	0	3	27
Management	8	4	6	3	54	4	2	35	18	16	150
Other	0	0	0	0	0	0	0	4	2	0	6
Unspecified	1	0	0	0	0	0	0	0	1	0	2

* Total number of projects active during 1981 and 1982.

** Many projects address more than one subject area, accordingly, the total number of projects under the subject category may exceed the total number of projects under each problem.

TABLE 3
HISTORICAL RESEARCH PROJECTS IN THE GREAT LAKES
(BY SUBJECT OF RESEARCH, 1975 AND 1976)

RESEARCH SUBJECTS	TOXIC ORGANICS	TOXIC METALS	PHOSPHORUS	NUTRIENTS	CONTAMINANTS - GENERAL	PATHOGENS	THERMAL DISCHARGES	OTHER	UNSPECIFIED	SEVERAL	TOTAL
NUMBER OF PROJECTS	55	22	12	45	90	22	13	137	77	62	535*
AS A % OF THE TOTAL	10 %	4 %	2 %	8 %	17 %	4 %	2 %	26 %	15 %	12 %	
NO. OF PROJECTS DEALING WITH:**											
Source and Loading	12	3	3	7	21	6	0	18	7	26	103
Characteristics	4	5	0	1	7	1	0	8	2	7	35
Fate and Transport	28	9	3	19	40	4	4	53	8	26	194
Environmental Impacts	10	9	3	18	16	2	6	21	27	18	130
Human Health Effects	3	1	0	0	1	2	0	0	1	0	8
Method Dev. & Modeling	18	6	4	14	23	6	4	54	21	10	160
Criteria	2	1	0	0	2	3	2	5	1	3	19
Management	7	2	2	12	35	4	4	25	25	16	132
Other	0	0	0	0	0	0	0	1	0	1	2
Unspecified	0	0	0	0	0	0	0	2	5	0	7

* Total number of projects active during 1975 and 1976.

** Many projects address more than one subject area, accordingly, the total number of projects under the subject category may exceed the total number of projects under each problem.

1. Toxic Organics

Initial concerns about organic contaminants arose from the use of organochlorine pesticides such as DDT. While these pesticides are effective in controlling insect pests and hence improve agricultural productivity, most are found to persist in soil and sediment, and to accumulate throughout the food chain. Evidence mounts that such contaminants are a potential cause of diseases, behavioural abnormalities and physiological malfunctions in both aquatic life and man.

Various other organic chemical contaminants have been entering the Great Lakes system by direct introduction, through atmospheric fallout (PCBs and combustion process products including PAHs), in sewage, by surface runoff, and/or via groundwater leachate. Many of these toxic substances can be classified as hazardous because of their widespread use, bioaccumulation potential and environmental persistence.

With the introduction of these foreign substances into the Great Lakes ecosystem, concerns have arisen regarding the safety of using the lakes as sources of fish and drinking water. Mirex residues in Lake Ontario fish and PCB residues in Lake Michigan fish attained concentrations high enough to warrant human health advisories against the consumption of fish from these lakes. In response to these concerns, a number of studies have been and are being undertaken to assess the hazards and risks to human health and the environment from persistent organic contaminants in the Great Lakes . Furthermore, since such persistent toxic organics pose a basinwide problem, these substances have recently emerged as the priority research problem in the Great Lakes.

Currently there are 94 projects dealing exclusively with toxic organics, compared with a total of 55 historical projects. A few additional projects investigating several problems include the problem of toxic organics. These are classified under the "several" group.

The emphasis of past research was on the fate and transport of organics in the Great Lakes and on method development and modeling*. There were moderate efforts to determine the sources and loadings of organics and their environmental impacts. Conversely, little attention was given to characteristics, human health implications, or to the establishment of water quality criteria. Meanwhile, some research efforts were directed towards the management of toxic organics in the Great Lakes.

Current research still emphasizes fate and transport as well as method development and modeling. In addition, there is an increased effort in the areas of environmental impacts and chemical characteristics. Human health implications, criteria development, and the management of toxic organics are still receiving insufficient attention.

Approximately 45 percent of the current toxic organic research focuses on pesticides and PCBs. Historically, these contaminants have accounted for over 65 percent of the research effort. It appears that research activities have been expanding to include other chemicals such as dioxins, benzenes, phenols and benzofurans.

With the emergence of toxic organics as a priority issue, there has been a significant increase in research efforts directed towards characteristics, fate and transport, environmental impact, human health effects, method development and modeling, as well as criteria development. The increase in the number of projects addressing chemical characteristics is attributed to the development of structure-activity relationships. Increases in environmental impact studies are attributed to toxicity research. The surge in method development is attributed to the advancement in measurement technology, and the interest in modeling reflects the need for predictive capabilities to elucidate the mechanisms of fate and transport.

* The terms included in the classification system (Table 1) will be used throughout this report to identify the problem of research, the subject of research and the area of activity which also refers to the source of the problem. Some readers may find that the structures of many sentences are affected by the use of these definitive terms.

2. Toxic Metals

Unlike man-made organic contaminants, trace elements such as metals are derived mainly from natural sources, i.e. earth's crust, and are detectable in at least trace amounts in the cleanest of lakes. With the coming of European settlements in the mid-1800's, metal loadings into the Great Lakes from geological sources increased because deforestation enhanced erosion rates. The rapid growth of heavy industries contributed to the problem as metals became extensively used in manufacturing processes. Wastewater discharges from industrial areas often contain calcium, chromium, cadmium, copper, mercury, nickel, lead and zinc.

Of the various metals, lead and mercury were discovered to have the highest bioaccumulation and bioconcentration potential because they can be methylated by microorganisms. Methylmercury and dimethylmercury are powerful neurological toxicants. While lead methylation has not yet been demonstrated in the Great Lakes, the Pollution from Land Use Activities Reference Group (PLUARG) concluded that if high lead loading persists in the Great Lakes basin, the potential for lead methylation exists. Like other toxic organics, organometallics represent a potential threat to human health and to other organisms.

Numerous other metals, among them selenium and copper, exhibit toxic effects dependent on their concentration and ionic dissociation. Water characteristics often can modify these effects.

Because of their bioaccumulation potential, toxicity, and widespread usage which has caused elevated levels, metals have become a concern in the Great Lakes basin. Excessively high mercury levels in fish forced the closing of the commercial fishery in Lake St. Clair in 1970. As of 1981, however, mercury levels in fish have dropped and limited commercial fishing has again been permitted. Other warnings have been issued periodically on the hazards of consuming mercury contaminated fish from the Great Lakes.

The toxic metals research effort has remained virtually unchanged from the period 1975-1976 to 1981-1982. While 22 projects were identified as exclusively researching toxic metals in 1975-1976, these numbers have increased by only three since that time for the same group of research institutions. Furthermore, many other multi-contaminant investigations have been or are addressing toxic metals. Most of these recent investigations are devoted to toxic organics as opposed to nutrients in combination with toxic metals.

The emphasis on various research subjects did not shift significantly from 1975-1976 to 1981-1982. Research efforts on fate and transport, environmental impact, and method development and modeling continue to dominate. Most of this effort continues to focus on lead and cadmium, which respectively account for four and three projects in both the historical and current analyses. Only one project has been identified as addressing the human health effects of metals. The most notable change has been the increase of research on metals associated with sediment and suspended solids.

3. Phosphorus

Under natural conditions many lakes eventually become filled with sediment and other materials from streams draining their watersheds and from rain and dust which fall directly on the basin over an extended time. Man's activities in many cases, however, have accelerated this natural aging process. Excessive loadings of nutrients from industrial, municipal and agricultural sources promote algal growth and cause eutrophication. Eutrophication quite often impairs water quality. It reduces the transparency of water, depletes dissolved oxygen and affects intolerant fish species and other biota.

Of the nutrients involved in the eutrophication process, researchers have found that phosphorus is the growth limiting nutrient. Soluble phosphorus, as opposed to soluble nitrogen and ammonia, is most likely to be depleted in lake waters during the growing season. By reducing the amount of phosphorus from municipal treatment plants and urban and agricultural runoff, the eutrophication process can be slowed and/or reversed, especially in lakes with shorter water replacement time such as the lower Great Lakes.

Between 1975-1976 and 1981-1982 projects exclusively devoted to phosphorus research have increased from 12 to 17. Multi-pollutant studies that include phosphorus, however, have decreased. One reason for the increase of phosphorus research is the emergence of fate and transport investigations, particularly bioavailability studies. Since the mid-1970's, greater emphasis has been placed on the management of municipal and other point sources of phosphorus. Historically, some emphasis was also placed on investigating non-point sources.

The relative proportions of the research in the various subject areas have remained unchanged. While source and loadings, fate and transport, environmental impact, method development and modeling, and management research continue to receive relatively similar treatment, criteria research continues to be non-existent.

4. Nutrients

Other nutrients, such as nitrogen and carbon, are also necessary to sustain algal blooms in the eutrophication process. In the Great Lakes these nutrients do not generally limit growth.

Nitrogen is a limiting nutrient in some nearshore and embayment areas of restricted circulation. Several species of blue-green algae, however, can fix atmospheric gaseous nitrogen if nitrates and nitrites are in short supply. Nitrate and nitrite nitrogen can also be a local water quality problem when they contaminate potable water supplies.

Carbon from natural sources, in the form of carbon dioxide, is found in abundant amounts to permit massive growths of algae during the eutrophication process, if other nutrients are in sufficient supply.

There has been a significant drop from 45 to 23 projects in research focusing exclusively on nutrients since the mid-1970's. A corresponding decrease has also occurred for multiple-pollutant projects involving nitrogen investigations, but not at the same rate. Only research in the source and

loading and the environmental impact field has remained fairly constant over time. Criteria research continues to receive minimal attention.

5. Contaminants - General

Various other contaminants which enter the Great Lakes are either directly toxic to man or affect the uses of water. These contaminants include asbestos, chlorides, cyanides, oxygen consuming organic contaminants and radionuclides.

Asbestos and radionuclides are natural contaminants in the Great Lakes basin because of rock weathering. Man's settlement of the basin, however, has resulted in higher loadings, which pose a potential human health hazard.

Cyanide occurs naturally as an intermediate metabolite. With the advent of the mining industry, significantly higher loadings of cyanide in the basin can pose a potential health threat to man.

Chloride levels in the basin have been steadily increasing because of industrial and urban expansion, and winter road deicing practices. High chloride levels can pose local drinking water problems and can possibly shift the phytoplankton composition of lakes to the more salt-tolerant species.

The number of projects investigating contaminants - general has increased significantly between 1975-1976 and 1981-1982. Greater emphasis is being placed on method development and modeling, management, environmental impact, and to some extent on criteria research.

6. Pathogens

It has long been recognized that water can serve as a vector in the transfer of disease. Cholera, typhoid, swimmer's itch and ear infections can be caused by various pathogenic bacteria, viruses and other organisms which originate in the fecal discharge of diseased persons or wildlife. Other forms of bacteria, such as fecal coliforms, are found in the intestinal tracts of

warm blooded animals and are eliminated in large numbers in their feces. Consequently, fecal coliform have been used to indicate the potential presence of pathogenic microorganisms in water.

Although epidemic diseases such as cholera and typhoid have not occurred for some time in the Great Lakes basin, high bacterial levels from 1975-1977 prompted the closing of 18 recreational beaches for periods ranging from three to 52 weeks along the shoreline. Beaches today periodically display high coliform levels, especially following heavy rains. Such periodic and isolated outbreaks of unsafe bacterial levels indicate that generally bacterial pollution constitutes a localized and short term problem. Further, Great Lakes circulation patterns tend to dissipate bacterial concentrations rather quickly, except in areas of restricted circulation.

The number of projects devoted to investigating pathogens has decreased approximately 36 percent since the mid-1970's. Most of this decrease has been in method development research, which dropped from six projects to one. Other research areas have remained fairly uniform. Approximately 25 percent of the current and historical projects continue to be in the municipal point source field.

A small number of multi-pollutant associated pathogen projects were identified and they remained relatively unchanged over time.

7. Thermal Discharges

Most of the life forms associated with the aquatic environment are essentially cold blooded or poikilothermic; as such they are acclimated and regulated by the prevailing water temperature regime. Water used by industry for cooling purposes and usually returned to a given lake or stream an average of $10^{o}C$ warmer alters the metabolism, survival and reproductive abilities of aquatic plants, invertebrates and fish. Fish, for example, may hatch too soon to find adequate food supplies. The food chain ultimately depends on plants whose abundance is dictated by the presence of daylight and temperature.

The sanitary and aesthetic qualities of a water body are affected by thermal discharges. Biological activity and the biodegradation of organic material increase with higher water temperatures, accelerating the consumption of oxygen, and lowering dissolved oxygen levels. Higher temperatures can also magnify the effects of some toxicants.

Only five of the current projects reviewed address thermal discharges in the Great Lakes. Historically, 13 projects addressed thermal discharges between 1975-1976, with over 60 percent of these projects concerned with industrial point sources. A major aim of this research was to understand the possible environmental impacts of such discharges.

8. Other

With the adoption of the ecosystem approach, it is generally recognized that an understanding of the physical, chemical and biological processes in the Great Lakes is a necessary pre-requisite to the effective management of water quality. While past research generally considered the chemical and biological features of the Great Lakes, it did not sufficiently consider the physical mechanisms vital to predict the fate, transport and/or distribution, and transformation of the various contaminants plaguing the Great Lakes.

The erosion of soil by water and wind is one example of a physical process important in the management of Great Lakes water quality. Sediment often is an important carrier of various contaminants. It also silts valuable fish spawning grounds and reduces the water storage capacity of some lakes and streams.

The number of projects investigating "other" research problem areas has decreased approximately 47 percent, from 137 in 1975-1976 to 73 in 1981-1982. This trend suggests that researchers are now more aware of the specific problems affecting Great Lakes water quality. While past projects investigating the abiotic component (physical environment) accounted for 26 percent of the research effort, only 16 percent of the current projects involve similar investigations. The research effort on suspended solid/sediment and/or erosion has also been decreasing since the

mid-1970's. Although such research is still accounting for 33 percent of "other" research, the total project numbers have decreased.

With the reduction in project numbers, there has been a corresponding decrease in most of the research subject areas. The only exception is management research, which has increased 40 percent, from 25 projects in 1975-1976 to 35 in 1981-1982. The majority of this increase relates to projects in the information and education field.

9. Unspecified

The number of projects not specifying the water quality parameter(s) being investigated has decreased by 68 percent from 77 projects in 1975-1976 to 25 in 1981-1982. The trend away from poorly defined research indicates that currently research managers are designing their programs to respond to specific issues.

Broad spectrum pollution or water quality studies accounted for 43 percent of the historical projects. An additional 35 percent focused on environmental impacts and/or assessment studies. While both types of investigation have dropped significantly since the mid-1970's, projects dealing with information and education have become dominant in the current research effort.

AREAS OF ACTIVITY (SOURCES OF POLLUTION)

To ensure compliance with the general and specific objectives outlined by the 1978 Great Lakes Water Quality Agreement, Article VI specifically directs the Governments of Canada and the United States to support programs and measures in the following source areas:

1. Airborne Pollutants,
2. Pollution from Dredging Activities,
3. Pollution from Industrial Sources,
4. Pollution from Municipal Sources,

5. Pollution from Shipping Activities, and
6. Pollution from Non-point Sources including Agricultural, Forestry, and Other Land Use Activities.

After reviewing the summaries of the total number of projects addressing each area of activity (Tables 4 and 5), the Board found that a large number of projects did not specify the area of activity of the research. This may indicate that research scientists are concerned more with the characteristics of the problem and its environmental and health implications rather than with its source (area of activity).

For the projects which did provide adequate information on the area of activity being investigated, the Board has reached several conclusions.

1. Atmospheric Source

The vast quantities of both natural and man-made gaseous and particulate materials found in the atmosphere are attributed to emissions. The distance emitted material travels downwind depends upon the height of the emission above the surface, the nature of the material, and meteorological conditions. Most materials eventually return to the surface either by dry particulate fallout, gas diffusion or precipitation washout.

With the heavy industrialization of North America and the traditional usage of tall stacks as a dispersal means to reduce local contaminant levels, atmospheric transport and deposition has become a major pathway for the influx of contaminants into the Great Lakes.

The number of projects investigating the atmosphere as a source of pollution to the Great Lakes has not changed significantly between 1975-1976 and 1981-1982. There has been, however, a dramatic change in the area of research, shifting to toxic organic, metal, and contaminants - general, (comprising 14 of the 22 projects currently addressing atmospheric sources) from "other" and "unspecified" research (comprising 16 of the 26 projects conducted in the past).

TABLE 4
CURRENT RESEARCH PROJECTS IN THE GREAT LAKES
(BY AREA OF ACTIVITY, 1981 AND 1982)

RESEARCH ACTIVITIES (SOURCES)	TOXIC ORGANICS	TOXIC METALS	PHOSPHORUS	NUTRIENTS	CONTAMINANTS - GENERAL	PATHOGENS	THERMAL DISCHARGES	OTHER	UNSPECIFIED	SEVERAL	TOTAL
NUMBER OF PROJECTS	94	25	17	23	122	14	5	73	25	53	451*
NO. OF PROJECTS DEALING WITH:											
Atmospheric Source	4	4	0	0	6	0	0	3	0	5	22
Dredging	0	2	0	0	1	0	0	4	1	3	11
Industrial Source	7	2	0	0	15	0	5	8	2	5	44
Municipal Source	4	2	7	1	7	4	0	3	0	7	35
Shipping	0	0	0	0	0	0	0	1	0	0	1
Non-Point Source	1	0	1	1	8	0	0	13	0	4	28
Other	3	0	0	0	1	0	0	5	0	0	9
Unspecified Sources**	72	15	9	19	61	10	0	28	21	19	254**
Several Sources	3	0	0	2	23	0	0	8	1	10	47

* Total number of projects active during 1981 and 1982.

** The researcher is probably concerned with the characteristics of the problem or its potential impacts on the environment regardless of its source(s).

TABLE 5
HISTORICAL RESEARCH PROJECTS IN THE GREAT LAKES
(BY AREA OF ACTIVITY, 1975 AND 1976)

RESEARCH ACTIVITIES (SOURCES)	TOXIC ORGANICS	TOXIC METALS	PHOSPHORUS	NUTRIENTS	CONTAMINANTS - GENERAL	PATHOGENS	THERMAL DISCHARGES	OTHER	UNSPECIFIED	SEVERAL	TOTAL
NUMBER OF PROJECTS	55	22	12	45	90	22	13	137	77	62	535*
NO. OF PROJECTS DEALING WITH:											
Atmospheric Source	1	1	2	2	1	1	0	12	4	2	26
Dredging	1	1	0	0	4	0	0	4	2	4	16
Industrial Source	4	2	0	2	12	0	8	3	1	6	38
Municipal Source	3	1	2	0	8	4	1	4	7	1	31
Shipping	0	0	0	0	4	0	0	0	1	2	7
Non-Point Source	1	3	1	4	10	0	0	33	3	12	67
Other	3	1	1	2	4	0	0	20	5	1	37
Unspecified Sources**	39	13	4	32	37	15	4	54	44	25	267**
Several Sources	3	0	2	3	10	2	0	6	11	9	46

* Total number of projects active during 1975 and 1976.

** The researcher is probably concerned with the characteristics of the problem or its potential impacts on the environment regardless of its source(s).

In addition to those projects discussed above, various other projects investigated atmospheric sources of pollution as just one aspect of their study. Approximately 17 current and 11 historical projects fall into this category.

2. Dredging

Natural processes such as erosion eventually fill in the bottoms of some rivers and certain parts of the lakes over time. With man's settlement in the Great Lakes basin, this sedimentation has rapidly accelerated. It became necessary to excavate and dispose of the bottom sediments at various locations in the open lake to maintain proper navigation channel depths in harbours.

Disposal practices were later found to cause water quality problems. During the transfer or redistribution of dredged materials into the open lakes, high concentrations of toxic metals, oil and grease, nutrients, and oxygen consuming wastes associated with the sediment are released into the water column. Consequently, to avoid additional pollution of the Great Lakes, it has become necessary to develop alternative dredge disposal practices.

The number of projects exclusively investigating dredging activities in the Great Lakes dropped slightly from 16 in the mid-1970's to 11 currently. The decrease can be attributed to a reduction in contaminants - general research from four projects to one. A shift away from generalized environmental impact assessment to more specific bioassay and bioavailability investigations in the dredging field are also noted.

3. Industrial Source

Various lakes and tributaries in the Great Lakes basin are receiving industrial wastes. Depending upon the nature of the industry, the wastewater effluents contain contaminants that may pose a threat to public health: toxic organics, metals, arsenic and cyanides; and/or wastes which disrupt plant and animal life cycles including oxygen consuming organics, nutrients, and other trace organics.

While industrial wastes are treated prior to discharge, many of the chemicals are not removed by biological sewage treatment processes and require other special treatment. Consequently, industrial wastewaters pose more complicated problems than municipal wastewaters.

While specific programs to reduce industrial point source inputs into the Great Lakes have produced improved water quality since the mid-1970's, industrial activities still constitute a significant source of toxic substances.

Between 1975-1976 and 1981-1982, the number of projects exclusively investigating industrial activities has slightly increased. Within the various research areas, however, less attention has been directed toward industrial thermal discharges. Management research accounts for the greatest effort in the industrial activity area for both historical and current research. In addition to those projects undertaken exclusively in the industrial activity area, there are a number of projects investigating industrial activities in combination with municipal sources. Most of these cases investigate wastewater treatment.

4. Municipal Source

Municipal point source wastewaters traditionally contributed to both local and lakewide pollution of the Great Lakes. Pollutants in these wastewaters include dissolved and suspended solids, oxygen consuming organic matter, oils, toxic materials, pathogenic bacteria and nutrients. If industries are connected to municipal sewage systems, their wastes will also be in these wastewaters.

Generally, municipal point source pollution can be reasonably controlled by current treatment technology and disposal methods. Since municipal point sources are stringently controlled by government regulations, the actual characteristics of the wastewaters are known and the quantity of flow, based on the sewered population, is predictable.

Approximately seven billion dollars have been committed by Canada and the United States to construct and improve municipal wastewater facilities in the Great Lakes basin since the early 1970's. As a result, consistent decreases in annual phosphorus loads to the lower Great Lakes have occurred.

The number of projects undertaken in the municipal field has increased slightly from 31 in 1975-1976 to 35 currently. The shift in emphasis has been away from the unspecified research category toward more phosphorus and multi-contaminant investigations. The management aspect continues to dominate efforts in the municipal activity field.

5. Shipping

Because of mobility, ships pose a unique pollution problem. Vessels can be the source of several pollutants: human excreta, garbage, litter and oils, as well as bilge and ballast water which may include various hazardous chemicals, oils, or nutrients. Accidental spills of dangerous cargos, although rare in the Great Lakes, can be significant.

Of the various activities outlined by the 1978 Agreement, pollution from shipping activities has been given the lowest research priority. Between 1975-1976 and 1981-1982, the number of research projects investigating such activities in the Great Lakes decreased from seven to one. Past research emphasized the management of these sources by wastewater treatment or disinfection.

6. Non-point Source

Non-point or diffuse source refers to runoff of water from land and includes tributaries, ditches, groundwater, storm and combined sewers. With improved wastewater treatment for point sources, land runoff emerges as a major contributor of nutrients, sediments and toxic substances in the Great Lakes.

Under the 1972 Great Lakes Water Quality Agreement, the Pollution from Land Use Activities Reference Group (PLUARG), which consisted of nine United States and nine Canadian representatives, was created to investigate pollution of the Great Lakes system from agriculture, forestry and other land use activities. Drainage from cultivated fields, livestock feedlots and land application of manure were found to be important diffuse sources of pollution. PLUARG's research identified other important diffuse sources, namely seepage and erosion from surface mining, and urban drainage from industrial and residential areas.

The non-point source activity area received the most attention in the mid-1970's with 67 research projects. Since the mid-1970's, however, this research effort has gradually decreased to 28 projects.

The majority of this drop has been in projects investigating the source and loading subject area. Historically, such research accounted for 52 percent of the effort (35 of the 67 projects reviewed). Currently, source and loading research accounts for only nine projects.

There has also been a 61 percent reduction in fate and transport research since the mid-1970's (from 33 historical research projects to 13 current ones).

7. Other

Projects classified under "other" include research in areas which may not be related to a source, such as physical limnology, natural ambient water quality investigations and the development of better instrumentation and equipment for water quality studies. According to the research review, there has been a significant trend away from this type of research towards source related problems.

8. Unspecified

A significant number of the projects reviewed lacked information on the area of activity or source of the problem being addressed. This problem has persisted with time as denoted by the 267 historical and 254 current

projects. The large number of unspecified projects observed during this review may indicate that there is more interest in the effects as opposed to the source of the problem.

Expenditure for Research

INTRODUCTION

In response to the Board's request, the research institutions included in this review provided information on annual funds allocated for each of their current projects. A large number of the historical projects reported in the Board's 1976 Research Directory, however, did not include information on funding. Appendices V and VI include the available information on funding for current and historical projects, respectively.

Inconsistencies can be seen in the initial reporting of research funds. Some institutions reported total expenditures, including salaries and maintenance; while others reported only operating budgets and excluded salaries. Some institutions were unable to define their expenditures on a project by project basis for Great Lakes research alone because the same resources, including personnel and facilities, are used for other functions. In some cases, the scope of the project was broad but only some of its elements were relevant to Great Lakes water quality.

The expenditures reported by the institutions are the on-the-record funds allocated for each project regardless of the degree of pertinence to Great Lakes water quality issues. To avoid confusion, the Board decided to record the funds exactly as reported by the various institutions (Appendices V and VI) . For this review, however, the Board decided to obtain more representative estimates of expenditures specifically related to Great Lakes water quality research. Accordingly, the Board requested each research institution to provide estimates of its total expenditure for Great Lakes research, including salaries, for the years 1975, 1976, 1981 and 1982 (Appendix I, Correpondence C). The information was used to adjust the totals of the previously reported expenditures. The following discussion, therefore, is based on the data as corrected by these estimates.

EXPENDITURE BY RESEARCH PROBLEM

The Board used the information on research funds to determine collectively the order of magnitude of expenditure for Great Lakes research by all institutions reviewed in Canada and the United States. A distinction was not made between the value of Canadian funds and that of United States funds. Comparisons were also not made between the expenditures of the various institutions.

Expenditures for each problem area by all institutions in 1975, 1976, 1981 and 1982 are included in Table 6.

Comparing expenditures in 1975 and 1976 with those in 1981 and 1982 revealed a shift in research emphasis. Past research tended to be less specific with regard to the nature of the problem being addressed. The expenditure for nonspecific projects has decreased from 31 percent in 1975 to seven percent in 1982. Meanwhile, there has been a significant increase in the expenditure for toxic organics and toxic metals projects. The former accounts for 19 percent of the expenditure in 1982 as opposed to three percent in 1975 and the latter accounts for five percent in 1982 as opposed to one percent in 1975. Total expenditures for the problem of eutrophication has not varied significantly over the last eight years. However, increased emphasis on phosphorus accounts for three percent of the expenditure in 1981 and 1982, compared with only one percent in 1975 and 1976.

Expenditures for pathogen and thermal discharges research have been relatively consistent over time.

Despite the shift in emphasis to research addressing specific water quality parameters, contaminants - general research in 1982 accounts for 23 percent of the funding, representing a major portion of the expenditure allocated for Great Lakes research. Similarly, projects classified as "others" accounts for 18 percent of the funding in 1982. A possible explanation of this trend may be that research scientists are attempting to address Great Lakes water quality problems by utilizing the ecosystem

TABLE 6

EXPENDITURE FOR GREAT LAKES RESEARCH*

(By Research Problem)

RESEARCH PROBLEM	FISCAL YEAR**							
	1975 ($ millions)		1976 ($ millions)		1981 ($ millions)		1982 ($ millions)	
Toxic Organics	.5	(3%)***	.7	(3%)	3.9	(14%)	4.5	(19%)
Toxic Metals	.2	(1%)	.3	(1%)	1.0	(4%)	1.3	(5%)
Phosphorus	.1	(1%)	.1	(1%)	0.8	(3%)	.6	(3%)
Nutrients	1.2	(7%)	1.1	(4%)	1.6	(6%)	1.7	(7%)
Contaminants - general	2.8	(15%)	9.0	(37%)	8.8	(32%)	5.3	(23%)
Pathogens	.2	(1%)	.2	(1%)	.3	(1%)	.1	(1%)
Thermal Discharges	.4	(2%)	.4	(2%)	.1	(1%)	.5	(2%)
Other	1.7	(9%)	1.7	(7%)	4.7	(17%)	4.2	(18%)
Unspecified	5.7	(31%)	5.8	(24%)	2.3	(8%)	1.6	(7%)
Several	5.5	(30%)	5.0	(20%)	3.9	(14%)	3.5	(15%)
TOTAL	18.3		24.3		27.4		23.3	

* Data included in this table have been adjusted to accurately reflect expenditures for Great Lakes research. Adjustments are based on additional information provided by research institutions (Appendix I, Correspondence C). Funds are not corrected for inflationary factors.

** Fiscal Years vary within calendar years for Canada and the United States. Expenditures included on this table represent totals of Canada and the United States for each Fiscal Year regardless of such variations. No distinction is made between Canadian and United States dollars.

*** As a percentage of the total expenditure of each Fiscal Year.

approach. Using this approach, all components of the Great Lakes ecosystem are to be considered when specific problems such as toxic substances or eutrophication are addressed.

EXPENDITURE BY AREA OF ACTIVITY

Summaries of the expenditure for Great Lakes research by area of activity (source) are included in Table 7. From this table it can be discerned that expenditures related to atmospheric sources have increased significantly from two percent and one percent in 1975 and 1976 to five percent and seven percent in 1981 and 1982, respectively. Similarly, the expenditure related to industrial sources has increased from two percent in 1976 to nine percent in 1982. Conversely, the expenditure affiliated with non-point sources has decreased from 32 percent in 1976 to nine percent in 1982. Meanwhile, the expenditure for dredging activity showed a temporary increase in 1976 but declined to two percent in both 1981 and 1982.

The figures also indicate that municipal source expenditures have remained stable over time and that expenditures related to shipping activity have decreased from one percent in 1975, 1976 and 1981 to an estimated zero in 1982.

Because a significant number of the projects are classified under "several", the above figures may have been underestimated. A large number of projects consider more than one of the above specified areas of activity.

The decrease in the expenditure for projects classified as "other" and the increase for projects on "unspecified" sources suggest that current research efforts are increasingly concerned with the general implications of Great Lakes specific problems rather than with their sources.

TOTAL EXPENDITURES

The estimated total funds reported by the group of institutions reviewed indicate very little variation in expenditures between 1976, 1981 and 1982 (Table 7). It is important to emphasize, however, that inflation has caused the value of the dollar to decrease significantly between 1976 and 1982. It was not possible for the Board to obtain reliable fund estimates for 1983.

TABLE 7

EXPENDITURE FOR GREAT LAKES RESEARCH*

(By Area of Activity)

AREA OF ACTIVITY	FISCAL YEAR**							
	1975 ($ millions)		1976 ($ millions)		1981 ($ millions)		1982 ($ millions)	
Atmospheric Source	.4	(2%)***	.3	(1%)	1.4	(5%)	1.6	(7%)
Dredging	.3	(2%)	1.7	(7%)	.4	(2%)	.4	(2%)
Industrial Source	1.0	(5%)	.6	(2%)	1.3	(5%)	2.1	(9%)
Municipal Source	.9	(5%)	.7	(3%)	1.2	(4%)	.5	(2%)
Shipping	.2	(1%)	.1	(1%)	.1	(1%)	0	(0%)
Non-Point Source	2.5	(14%)	7.8	(32%)	2.3	(8%)	2.1	(9%)
Other	7.7	(42%)	7.9	(33%)	.9	(3%)	.9	(4%)
Unspecified Sources	4.4	(24%)	4.0	(16%)	15.5	(56%)	11.1	(48%)
Several Sources	.9	(5%)	1.2	(5%)	4.3	(16%)	4.6	(19%)
TOTAL	18.3		24.3		27.4		23.3	

* Data included in this table have been adjusted to accurately reflect expenditures for Great Lakes research. Adjustments are based on additional information provided by research institutions (Appendix I, Correspondence C). Funds are not corrected for inflationary factors.

** Fiscal Years vary within calendar years for Canada and the United States. Expenditures included on this table represent totals of Canada and the United States for each Fiscal Year regardless of such variations. No distinction is made between Canadian and United States dollars.

*** As a percentage of the total expenditure of each Fiscal Year.

Conclusions and Recommendations

INTRODUCTION

This research review indicates that Great Lakes scientists have generally responded in a timely manner to Great Lakes research needs. The emphasis of the early 1970's was on the problem of eutrophication. By the middle of that decade scientists confirmed that phosphorus is the nutrient most limiting to the growth of Great Lakes flora. In subsequent years scientists shifted their emphasis to the problem of toxic substances. Most recently they have become increasingly aware of the potential danger to human health and the environment from the presence of these substances in the Great Lakes ecosystem.

The development of events are reflected in the Great Lakes Water Quality Agreements of 1972 and 1978. The former emphasized programs to control phosphorus and the latter stressed programs and research needed to address the toxic substances problem. As programs under the two Agreements progressed, the Science Advisory Board and the Water Quality Board identified gaps in the knowledge required to solve critical problems and recommended methods for filling in these gaps.

The Science Advisory Board's research review indicates that Great Lakes scientists are attempting to fulfill the various requirements of the Agreement and are responding to the recommendations of the two Boards. However, despite these significant efforts, knowledge gaps remain for ten critical issues identified by the 1978 Agreement and in past Board reports (Table 8). The Board used the information contained in the data base to evaluate current efforts addressing these ten critical issues (Table 9). The Board found that eight of these issues are inadequately addressed and require additional emphasis and funding in order to meet future needs of the Great Lakes basin. The remaining two issues, structure-activity correlations and phosphorus management, appear to be adequately addressed based on project numbers and funding (Table 9). Key questions, nevertheless, remain unanswered in these two

TABLE 8

RECOMMENDED AREAS FOR ADDITIONAL RESEARCH IN RELATION TO THE 1978 AGREEMENT REQUIREMENTS AND SAB AND WQB RECOMMENDATIONS SINCE 1973

Research Areas	Agreement Requirements	Recommendations* SAB	WQB
1. Epidemiological Studies (Human Health)	Annex 12.4 (b) 12.7 (a) & (b)	79-1, 81-1,	73-1,2; 76-2; 81-1,4,5
2. Health of Aquatic Communities	Annex 12.4 (b)	79-1; 81-1	73-1; 76-2; 78-2,3; 81-1,4,5
3. Atmospheric Pollution Indicators	Article VI 1	81-4	81-6
4. PAHs and Toxaphene	Annex 12.5 (f) and 12.7 (c)		
5. Structure-Activity Correlations		81-1	81-2,3,5; 77-1 76-1
6. Tissue and Sediment Banks	Annex 12.5 (e)	81-1	
7. Computer Modeling and Validation	Annex 12.5 (g)	81-1,4; 80-1,2; 77-1	81-2,5; 77-1
8. Phosphorus Management		78-1	
9. Groundwater Contamination	Annex 12.3 (b) and 12.5 (f)	80-3	
10. Socio-Economic Considerations		81-4; 78-1	

* Numbering of Recommendations follows the order in which they were summarized in Appendix III.

TABLE 9

SUPPORT FOR CRITICAL AREAS OF RESEARCH

(TWO YEAR, 1981-82)

	RESEARCH RECOMMENDATION	NUMBER OF APPLICABLE PROJECTS	ESTIMATED SUPPORT ($ million)
1.	Epidemiological Studies (Human Health)	11	1.5
2.	Health of Aquatic Communities	15	2.0
3.	Atmospheric Pollution Indicators	5	0.1
4.	PAHs and Toxaphene	8	0.6
5.	Structure-Activity Correlations	15	2.0
6.	Tissue and Sediment Banks	2	0.1
7.	Computer Modeling and Validation	18	6.0
8.	Phosphorus Management	18	3.3
9.	Groundwater Contamination	6	0.2
10.	Socio-Economic Considerations	8	0.9
	TOTAL	106	16.7

research areas; therefore, the existing level of effort and resources should be maintained.

RESEARCH RECOMMENDATIONS

1. EPIDEMIOLOGICAL STUDIES (HUMAN HEALTH)

The Agreement calls for research efforts to identify the impacts and the significance of persistent toxic substances on human health. Research to identify the interactive effects of such substances on humans is also required by the Agreement.

To meet these requirements and to support the demands for human health surveys and analyses, which immediately follow an episode of environmental contamination, the data collected must be temporally and spatially specific enough to quantify real exposure levels that could cause potential biological damage.

The Board found that current projects investigating human health effects cover a variety of contaminants of concern and are not exclusive to epidemiological assessment. Accordingly, the data generally cannot be used to respond to assessment questions. Of the 451 projects currently funded, 18 address the human health effects of hazardous substances. Of those, only 11 involve specific studies which would generate epidemiological measurements on human exposure.

The Board concludes that existing research efforts addressing epidemiological effects of hazardous substances on humans is inadequate to fulfill Agreement requirements. Accordingly, the Board recommends that

more effort and funds be devoted to epidemiological research related to Great Lakes contaminants.

2. HEALTH OF AQUATIC COMMUNITIES

A major concern in the Great Lakes is the state of health of the aquatic biota. The Agreement calls for monitoring and research to identify the effects of persistent toxic substances on the living aquatic system. Currently, most toxic substances research has a regulatory orientation. Ambient levels are monitored more than the health of the living system. Without data on disease, parasites, and the biochemical and physiological responses of aquatic organisms to stress, the site specific ecological responses to an array of environmental stresses cannot be determined. Accordingly, the Board recommends that

more research effort be directed towards the study of the potential effects of hazardous substances on the health of aquatic communities.

3. ATMOSPHERIC POLLUTION INDICATORS

One area of research specified in the Agreement is the identification of airborne pollutant sources and their relative contributions of substances with potential significant effects on Great Lakes environmental quality.

Monitoring atmospheric deposition of pollutants in the Great Lakes is difficult and the data are hard to interpret because of the diffuse nature of this source. Consequently, the Board recognizes a need to identify and validate the use of a conservative indicator substance, such as the ratio of sulfur isotopes or vanadium to nickel, whose main transport mechanism is the atmosphere. Such indicators may prove to be a useful tool in determining the relative proportion of materials derived from differing sources.

Only five projects were found to be of any relevance to the identification of such an indicator. Accordingly, the Board recommends that

more research effort be directed toward the identification of conservative indicators of atmospheric inputs of toxic materials into the Great Lakes.

4. POLYNUCLEAR AROMATIC HYDROCARBONS (PAHs) AND TOXAPHENE

The Agreement not only calls for research leading to the identification of the sources of airborne pollutants, but it further states that research should be intensified to determine the pathways, fate and effects of toxic substances.

Both toxaphene and PAHs are persistent toxic substances and are suspected of entering the Great Lakes system via the atmosphere. The level of research and monitoring of PAHs in the Great Lakes basin is limited, but evidence from other research indicates that their loadings in marine and freshwater sediments are increasing. Some PAHs are carcinogenic to mammals; all occur naturally when wood, coal, or liquid hydrocarbons are burned.

Toxaphene is a complex mixture of toxic compounds produced by the chlorination of camphene which is a chemical product of turpentine distillation. Although found in Great Lakes fish, insufficient information presently exists to establish whether the reported concentrations of this substance constitute a threat to human health or the environment. There is also insufficient information regarding the toxicological characteristics of the various components of toxaphene. While some data implicate the atmosphere as the likely pathway for lakewide contamination, some scientists maintain that toxaphene-like compounds found in the Great Lakes may also be contributed from pulp and paper mill effluents. Camphene, found in the wood pulp, can be inadvertently chlorinated during the process of making paper. Information on the sources of toxaphene and its method(s) of transport is therefore needed.

The research review revealed that, while the number of projects investigating atmospheric sources has been relatively consistent with time, the emphasis has shifted toward the study of toxic organics and metals. In spite of this emphasis, scientists are unable to specify the nature, extent or potential health significance of PAHs and toxaphene in the environment.

The Board found four projects investigating PAHs, three on toxaphene and one studying both materials. Considering Agreement requirements for the identification of atmospheric pollutant sources and the level of current research effort, there is an urgent need for more data on PAHs and toxaphene. Therefore, the Board recommends that

more effort be devoted to determining the source, methods of transport, persistence and bioavailability of PAHs and toxaphene, and more emphasis be given to the study of their potential effects on human health and the environment.

5. STRUCTURE-ACTIVITY CORRELATIONS

The Agreement calls for the establishment of an early warning system consisting of several elements to anticipate future toxic substances problems. One of these elements is structure-activity correlations. Such correlations may be used as tools to screen the ever increasing number of toxic substances in the Great Lakes ecosystem. Since it is unlikely that the basic data set required to set ambient water quality standards and action levels for fish will ever be developed for every compound, structure-activity correlations are essential. The current research review identified 15 projects involving structure-activity correlation studies with a total budget of 2.0 million dollars. The Board considers that this effort is adequate, but strongly recommends that

the present level of support for structure-activity correlations research be maintained.

6. TISSUE AND SEDIMENT BANKS

The Agreement's requirement for an early warning system also calls for the establishment and maintenance of a sediment and tissue bank to permit retrospective analyses to establish trends.

The Board's research review identified only two projects which maintain a biological tissue or sediment specimen bank. Though 27 agencies have biological tissue banks, only six have ongoing archives, and only three cover all of the Great Lakes. Fish were being archived in these three cases.

The Board recognizes a need for an international specimen bank where specimens could be "finger-printed" by gas chromatography - mass spectrometry characterization; the results stored on a central computer for future use and comparison; and the remaining sample portions and their associated extracts stored to maintain chemical integrity. Analyses of the temporal and spatial distributions of suspected toxicants could then be performed on the "finger-prints" and retained for chemical validation. These analyses could then be used to focus future monitoring and research efforts on toxic substances at maximum benefit per unit effort. Research on improved methods of storage should be continued. The Board contends that the research effort devoted to the development of tissue and sediment banks is not adequate. The Board therefore recommends that

a central, international Great Lakes specimen bank be established and that additional efforts be devoted to the development of advanced methods for the preservation and characterization of samples and for the interpretation of results.

7. COMPUTER MODELING AND VALIDATION

The development and use of mathematical models to predict the consequences of various loading rates of different chemicals are another component of the early warning system specified within the Agreement.

Considerable effort has been expended on developing predictive simulation models for nutrients and toxicants in the Great Lakes. The developed models differ in the temporal and spatial scales in which they are applicable. Consequently, there is a need to determine which models are appropriate for a particular problem and to validate such models to enhance their utility. Such validation experiments would verify a model's capabilities and would have the added benefit of integrating monitoring and research activities.

Model validation is an expensive process. Therefore, only those models which have the most potential for applicability should be validated. Accordingly, the Board recommends that

a task force be established to evaluate efforts for selecting and validating computer simulation models.

8. PHOSPHORUS MANAGEMENT

Many of the mathematical models developed for Great Lakes management relate to the problem of eutrophication, particularly to phosphorus control efforts. The majority of the research efforts directed toward validating models occur in the nutrient management field. As a result of these efforts and the programs put in place to control phosphorus, the Great Lakes are responding to reduced phosphorus loadings.

It is still uncertain, however, whether existing point source controls are sufficient to achieve the desired level of lake recovery, or whether stringent non-point source control programs should be initiated as recommended by PLUARG and the Phosphorus Management Strategies Task Force. The major question of the bioavailability of phosphorus remains to be answered. The Board contends that the existing eutrophication model research effort is adequate, and recommends that

the current nutrient research effort be maintained, and that the post PLUARG management assessment models be subjected to in-depth evaluation and validation.

9. GROUNDWATER CONTAMINATION

The Agreement does not specifically reference groundwater contamination, but does call for monitoring to characterize the presence and significance of chemical residues; to identify sources of persistent toxic substances; to closely coordinate air, water and solid waste management programs, and to ensure proper waste disposal.

The Board concludes that though considerable research is being conducted on water quality problems in the Niagara River, projects are not adequately addressing groundwater migration as a transport mechanism for toxic substances.

Six projects examined Great Lakes contamination via groundwater; two of these specifically addressed migration from solid waste disposal sites.

Most occurrences of environmental contamination from existing solid waste disposal sites appear to be confined to localized shallow groundwater. The only identified exception in the Great Lakes basin appears to be the Niagara River. Groundwater in this case transports toxic substances to the river. Detailed mapping of the groundwater resources in the Great Lakes basin is required in order to assess the transport mechanism of toxic materials via this route. There is also a need for greater understanding of the technology to remove groundwater pollutants and to limit contamination of groundwater resources.

The Board therefore recommends that groundwater resources of the Great Lakes system be studied to determine potential contamination routes via this source and to establish mitigative measures.

10. SOCIO-ECONOMIC CONSIDERATIONS

Though the Agreement does not contain specific requirements for socio-economic research, it empowers the Science Advisory Board to seek expert advice on this issue as it deems necessary. It also empowers the IJC to direct its Water Quality Board to examine the appropriateness of Agreement programs in the light of socio-economic imperatives. The Board and PLUARG have therefore made related recommendations over the years.

The Board identified eight research projects currently being undertaken in the area of socio-economic research. Information on forestry, agriculture, housing and other economic activities that affect water quality in the Great Lakes was not compiled or assessed by the Board.

Water management policies and other developmental decisions undertaken in the Great Lakes basin will have dramatic repercussions on Great Lakes water quality and resources that directly support human activities. Studies of the economic implications of various strategies to implement the Great Lakes Water Quality Agreement have been recognized as necessary. Further, to the extent that other research priorities discussed previously imply management choices, socio-economic analyses are essential complements to the technical studies.

The Board therefore recommends that

research programs in the Great Lakes encompass socio-economic considerations and that particular emphasis be given to:

(a) assembling currently available socio-economic data relevant to the Great Lakes Water Quality Agreement;

(b) improving the measurement and documentation of economic and social implications of alternative strategies for meeting the water quality objectives;

(c) anticipating the water quality impacts of future basin economic activities, including demands for water uses; and

(d) performing research for (b) and (c) to develop a socio-economic component to be integrated with future policy and management options analysis.

AREAS OF CONCERN

In addition to the ten recommended research needs outlined above, the Board identified an issue which requires the immediate attention of the Great Lakes research community. This is the issue of the "areas of concern". These are geographic locations in the Great Lakes where water, sediment or fish quality are degraded. The Water Quality Board of the International Joint Commission has identified these areas in its 1981 and 1982 Annual Reports.

Of particular interest to this Board are the eighteen Class A areas where water quality is significantly degraded and beneficial uses impaired. In this class there are areas which, according to the Water Quality Board's 1982 report, have chronic problems that are not expected to be resolved despite the remedial measures currently in operation and proposed for these locations. For example, the sediment in the Buffalo River (New York) is heavily polluted with a variety of contaminants including nutrients, oxygen-consuming materials, heavy metals and polychlorinated biphenyls (PCBs). Similar problems were identified in Grand Calumet River and Indiana Harbor Ship Canal (Indiana), in the Rouge River and the Raisin River (Michigan), in the Maumee River, the Cuyahoga River, and the Ashtabula River (Ohio), and in Hamilton Harbour (Ontario). The Water Quality Board contends that even though all

reasonable remedial measures have been or are being taken, it is doubtful that the environmental problems in these areas will be reasonably resolved.

Therefore, the Science Advisory Board recommends that adequate efforts and the necessary funds be devoted to the development of research programs designed specifically to address the chronic problems identified in these areas of concern. (The ultimate objective of these programs is to find technically feasible and economically sound solutions to alleviate these problems.)

The formal mechanism described above often results in unavoidable delays. The Commission requires time to consider its advisors' reports before making recommendations to the Governments and the Governments need time to prepare their responses to these recommendations. Usually it takes two years or more for these events to occur. Accordingly, a minimum of two years will pass from the time the Board makes its recommendations until research resources can be allocated or shift in emphasis begins. If responses were dependent on the expected chain of events, and if the recommended research work were to require three years to complete, any research need would have to be specified at least five to six years before the results are made available for re-evaluation by the Board.

The Board maintains that only a few very general research needs can be forecast that far in advance. The Board therefore urges the Commission to seek a faster mechanism to obtain responses to the needs that are identified. Additionally, the public sector perceives research needs from time to time, needs that are often recognized because a problem has developed. A clear pathway for such needs to enter the system does not exist except when the Boards and the Commission recognize and act on such public concerns. More public input might facilitate the establishment of research programs more in accord with actual needs.

In addition to any formal transmittal of IJC recommendations, there is an informal transfer. The informal mechanism is much faster. It consists of distributing the reports and recommendations of the several IJC Boards and Committees to scientists and engineers responsible for developing research proposals. These scientists read the Boards' reports but seldom read the reports of the Commission itself and almost never the response of the Governments. Researchers match their expertise and agency mandates with the various recommendations. Agency managers, in turn, approve and fund the proposals as their mandates and resources permit. This process often predates any formal recommendations by the IJC or instructions from the Parties.

Examples of effective informal responses in both countries include:

1) The need for structure-activity relationships programs was discussed in a report of a workshop sponsored by the Research Advisory Board (now the Science Advisory Board) in March 1975. Subsequently, in its 5th annual report to the Parties in 1977, the IJC indicated its support for these programs. Before the formal statements were transmitted to the Parties, agencies represented on the Board (ERL in Duluth and GLFRB and NWRI at CCIW) initiated these programs.

2) The nature and bioavailability of toxic metal forms in the water column and sediments were described in a 1975 report from a workshop sponsored by the Research Advisory Board (now the Science Advisory Board). This topic has since been acted upon by NWRI at CCIW.

3) A recommendation for phosphorus controls from a PLUARG report has been acted upon by NWRI and the Pollution Control Branch of the Ontario Ministry of the Environment, but the Parties have not yet responded to the IJC recommendations on PLUARG.

Fortunately, in most instances the formal and informal transfer mechanisms elicit a suitable response from the research community to the IJC research needs. However, in some instances the needs of the IJC are quite divergent from the mandates of the agencies and therefore cannot be readily met. For example, few environmental agencies have public health responsibilities. Without formal arrangements on the part of the Governments to bring these needs into the programs of such agencies or to involve the agencies which may have such responsibilities, there will continue to be deficiencies in the area of health research.

To complement the formal and informal responses, the Board is proposing to the Commission another mechanism to help circumvent the delay in response to the recommendations and to increase cost effective cooperation among the implementing agencies. The Board therefore recommends

that the Commission endorse the formation of a Council of Great Lakes Research Directors to meet semi-annually under the auspices of the SAB to discuss mutual Great Lakes research programs in order to:

i) provide information exchange;

ii) coordinate Great Lakes research programs of mutual interest;

iii) ensure consistency of program elements and optimum resource applications; and

iv) respond to the evaluations and recommendations of the SAB and the IJC.

Although recommendations on research programs made to the agencies via the Science Advisory Board and the IJC are implemented at the agencies' discretion, it is important that the Science Advisory Board create a position from which it may analyse the response and results of IJC recommendations on Great Lakes research. The system of evaluation used in this report and based on research project descriptions does not allow a full appreciation of the content of the project. To overcome these difficulties and to satisfy the SAB's mandate outlined under Article V 2(a) of the Great Lakes Water Quality Agreement, it is therefore recommended that

the SAB in concert with the Council of Great Lakes Research Directors develop a system of research evaluation to assess the degree of implementation and success of agency research, as well as the response to research recommendations of the Commission.

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